STUDIES ON PADDY CULTIVATION

I. THE PADDY CROP IN RELATION TO MANURIAL TREATMENT—A GENERAL DISCUSSION

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THIS paper is the first of a series of studies on paddy cultivation in Ceylon. It has already been determined by experiment that manuring and transplanting of paddy give statistically significant increases of yield, and that the increases are economic, but it has never been asked how and why the increases take place, or whether the particular processes (which in the case of manuring are based on temperate experience) are the best that can be applied. It is the object of the present series of papers to answer some of these questions; to enquire of the plant itself whether the manure it is getting is the best mixture applied at the most favourable time, or whether the methods of cultivation are really responsible for increase in yield, and why.

The method to be adopted is to carry out randomised and replicated field experiments and at the same time to observe, by chemical analysis, what is happening in the plant and in the soil throughout the season. The first of these experiments has just been completed, and is described in the following pages; the more technical chemical data are omitted and appear separately in the second paper of the series. The experiment was the comparatively simple one of testing the effects of green manure (*Tithonia diversifolia*) at the rate of one ton per acre, superphosphate at the rate of one hundredweight per acre, a broad ratio ammonium phosphate at ninety-six and half pounds per acre, and a mixture of green manure and superphosphate at the above rates, against one another and against a control that received no manure. The experiment was carried out at the Experiment Station, Peradeniya during the *Maha* 1931-32 season, in $\frac{1}{100}$ acre plots with borders, randomised and replicated six times. Unfortunately one replication had to be discarded during the course of the experiment. The trial was carried on during the *Yala* season for the observation of residual effects. At the same time crop and soil samples were taken at all stages of growth and analysed, so as to determine the rate of absorption of fertiliser by the plant and the rate of loss from the soil. As Crowther says [7] "The elementary composition of the growing plant changes markedly with the stage of growth, and the key to many practical problems of manuring is to be found in the study of the uptake of nutrient elements in relation to the stage of development of the crop." The absorption of fertiliser by the crop should be accompanied by corresponding soil losses, but it is necessary to take soil analyses to confirm the assumption. Samples of both soil and plants were taken at various stages of the crop, seven such samples being taken during the *Maha* season and five during *Yala*. At each sampling analyses were made of nitrogen, dry matter, ash, phosphoric acid, potash, lime and silica in the whole plant and in leaf and stem and panicle or grain separately. By "whole plant" is meant the above-ground portions only; a very small portion of the food stays in the roots, and this is returned to the soil before the next crop is sown—the actual soil losses are in the portions of the plant harvested. The soil samples were analysed for total carbon and nitrogen contents, exchangeable bases (total potash, lime and ammonia), soluble phosphoric acid, and hydrogen ion concentration.

The same procedure will be followed in succeeding experiments of the series. The second experiment is now in progress, having been started during *Maha* **1932-33** and continued during *Yala* **1933**. It compares the efficiency of transplanting, broadcasting and thinning and broadcasting, in each case with and without manure, giving six treatments which are randomised and replicated five times. The results will give ten effective replications of systems of sowing and fifteen of the efficiency of manuring. At the same time costs are being taken so that the economics of the various methods can be determined. The third experiment of the series will commence in *Maha* **1933-34**, and will be an outcome of the experiment here recorded. It will endeavour to determine the relative efficiencies of different phosphatic fertilisers and the optimum time of application of fertilisers generally.

The results of cultivation in the first experiment are given in Tables I and II. From Table I it is seen that the application of a combination of nitrogen and phosphoric acid produces a considerable increase in yield, and that the application of these constituents separately results in a smaller increase. The results are significant, and the Standard Error of Mean Differences of 7·3 per cent. indicates that the odds are 100 to 1 that treatments 1, 2 and 3 are all significantly better than the control, that 1 and 2 are definitely better than 4 and that 1 is definitely better than 3; in other words, the results of previous experiments [5] are confirmed that phosphoric acid is the most important requirement of Ceylon paddy soils, and that the benefit to be derived from its application can be increased by the addition of some form of nitrogen. The results of *Yala* cultivation again show an increased yield where phosphoric acid had been added, but the increases are much less than in the previous crop, and are not significant. The lower yield is accompanied by a less amount of fertiliser constituents in the soil and also, as will be seen from the chemical data, by a lower percentage of these constituents in the plant. It will also be noted that the mean yield per plot of the control is 50 per cent. greater in the *Maha* season than in the *Yala*, but this is at least in part accounted for by the fact that the *Maha* crop is of 6½ months' duration whereas the age of the *Yala* crop is only 4½ months.

It now remains to discuss the general deductions to be drawn from the chemical data, taken in conjunction with the figures tabled above. The figures, supported as they are by previous results and by the results of other workers, demonstrate the value of manuring. "'The inexhaustible richness of tropical soils' is but seldom found in Nature" and "unless fertilisers are applied to the soil no tropical crop can for long continue to give high yields" [6]. It remains to be seen, however, whether the manures applied are in the form best suited for the work required of them, and whether they are being applied at the time when they will confer the greatest benefit on the crop.

It is obvious from the chemical data that (a) except in regard to dry matter, the percentage constituents of the crop generally diminish with advancing crop growth during both *Maha* and *Yala*, and are lower in the latter season than in the former. The percentage of phosphoric acid in the crop at any time is low when compared with that found in some countries, e.g. Hawaii [2], and is due to the low phosphoric acid content of our soils. (b) The composition of the crop does not show marked variation with treatment, and the effect of the fertiliser appears to be directed more towards increasing crop yield than to modifying its composition. Ammonium phosphate has, however, had the effect of increasing the percentage of phosphoric acid in the crop throughout the *Maha* season. (c) Under Peradeniya conditions the crop at flowering time has absorbed less than 50 per cent. of the nitrogen and phosphoric acid contained at harvest in the *Maha* crop, and on the average only about 30 per cent. of these constituents in the *Yala* crop. The lower *Yala* rates of absorption are probably connected with a shorter pre-flowering period (79 days against 112 days). The application of smaller doses of manure, one of which would be just before flowering, may be found to give better results. (d) When nitrogen is applied as ammonium phosphate it is totally absorbed, whereas when applied as green manure it is assimilated only to the extent of two-thirds. Where no nitrogen is applied the crop has drawn on the store of soil nitrogen, large losses from which are observed as a result of cultivation. (e) Phosphoric acid in the form of soluble fertiliser is absorbed by the crop to a total extent of only 20 to 25 per cent. of the quantity applied. Of the amount absorbed 80 to 85 per cent. is found in the *Maha* crop. In view of the fact that soluble phosphates are readily converted in paddy soils into insoluble compounds with hydrated iron and aluminium oxides, the result is not unexpected. (f) The soil data show that there is no noticeable difference between the water-soluble phosphoric acid contents of phosphoric-acid-treated and non-treated soils. The probability of "solid phase" feeding of phosphoric acid by the paddy plant is suggested. Viewed in the light of the above statements, the use of bonemeal as a fertiliser for paddy would thus appear to offer advantages. (g) The grain at harvest contains on the average 71 per cent. of the nitrogen and 82 per cent. of the phosphoric acid of the whole crop, while the straw has 86 per cent. of the potash and 78 per cent. of the lime. Nitrogen and phosphoric acid are thus the dominant fertilising constituents for grain production. (h) The amounts of fertilising constituents removed annually in the crop per acre are approximately 45 lb. nitrogen, 60 lb. potash, 15 lb. phosphoric acid and 25 lb. lime. The need for replacing these constituents if high yields are to be maintained is apparent. (i) The soil losses in nitrogen and calcium are considerably higher than the amounts of these constituents found in the crop. Denitrification and perhaps leaching of nitrogen, and leaching of calcium are responsible for the losses. The amount of potassium found in the crop is almost exactly identical with the exchangeable potassium lost from the soil. (j) The exchangeable ammonia content of the soil falls with increasing crop growth. It is generally higher in *Maha* than in *Yala*, and in the latter season does not vary to any appreciable extent from plot to plot. (k) The hydrogen ion concentration of the soil increases slightly on puddling, but diminishes as crop growth advances; the final P_H is slightly lower than the original figure.

DISCUSSION

Phosphoric acid is the limiting factor determining crop yield on Ceylon paddy soils. This is apparent from the results and is in accord with previous findings. When all plots are approximately equivalent in phosphoric acid content, nitrogen (or more correctly available nitrogen in the form of replaceable ammonia) becomes the limiting factor. This is seen from both seasons' results—from the *Maha* crop, where the addition of readily available nitrogen gives a significant increase over the addition of phosphoric acid alone, and in the *Yala*, where treatments 1 to 3 started with a small residue of phosphoric acid but with no available nitrogen, and no significant differences were obtained. The higher average yield during *Maha* is probably due to a combination of three factors, the longer period of growth, the higher replaceable ammonia content and the greater available phosphoric acid content of the soil; the influence of variety (*Mawi* was used for *Maha* and *Heenati* for *Yala*) must however not be forgotten.

Previous workers are in conflict over the optimum time of application of fertilisers. Sahasdrabudhe [4] suggests that manure should be applied in three stages—at transplanting, before flowering and in the milk stage, but he appears to be most concerned with the loss of fertiliser by leaching. If that were the main factor one would agree with him, but the rate of availability of the manure must be taken into account, and late application of manure may result in some being still in a non-assimilable form by the time the crop is harvested. On the other hand Kelley and Thompson [1] advocate the early application of manure on the ground that the greater part of the fertiliser constituents are absorbed during the first two-thirds of the plant's life. The figures do not agree with those obtained in the present experiment, and it is obvious that the problem requires further investigation. It has been stated above that only 20 to 25 per cent. of phosphoric acid reappears in the plant. Of that quantity it is assumed that a small amount becomes available at once and that the rest is locked up in a form which, while not immediately available, becomes so during the life of the plant. The optimum results will be obtained when the immediately-available portion is completely absorbed and the slowly-available portion is made available before harvest; whether those results will be obtained by applying one dose or several doses has yet to be determined and will be the subject of the next experiment.

REFERENCES

1. KELLEY, W. P. AND THOMPSON, ALICE R.—A Study of the Composition of the Rice Plant.—*Hawaii Agric. Exp. Stn.* Bull. No. 21, 1910.
2. KELLEY, W. P.—The Assimilation of Nitrogen by Rice.—*Hawaii Agric. Exp. Stn.* Bull. No. 24, 1911.
3. SEN, J. N.—A Study in the Assimilation of Nutrients by the Rice Plant.—*Agric. Res. Inst. Pusa*, Bull. No. 65, 1916.
4. SAHASDRABUDHE, D. L. Assimilation of Nutrients by the Rice Plant.—*Bombay Dept. Agric.* Bull. No. 154, 1928.
5. Administration Report of the Director of Agriculture, Ceylon, for 1930, p. D83.
6. VAGELER, P.—An Introduction to Tropical Soils.—Macmillan & Co., 1932.
7. CROWTHER, E. M.—Soil and Fertilisers.—Rept. from Reports of Appd. Chem. Vol. XVII, 1932.

TABLE I

PERADENIYA PADDY STATION

Season Maha 1931-32

Manurial Trial on $\frac{1}{100}$ Acre Plots

Yields in Pounds

Treatment	Replications a	b	c	d	e	Total	Mean	Per cent.	Remarks
Ammonium phosphate (wide ratio) 96½ lb./acre	23·1	28·4	26·6	26·0	23·7	127·8	25·6	159·7	Applied after final levelling
Superphosphate 1 cwt./acre + Green manure 1 ton/acre	18·2	27·6	22·5	22·4	21·0	111·7	22·3	139·6	Applied 7 days before transplanting
Superphosphate 1 cwt./acre	21·2	24·2	22·1	20·4	16·7	104·6	20 9	130·7	do
Green manure 1 ton/acre	21·0	25·2	17·7	16·8	11·4	92 1	18·4	115·1	do
Control	13·4	25·2	16·0	12·1	13·3	80·0	16·0	100	
Block totals	96·9	130·6	104·9	97·7	86·1	516·2	20·6		

Analysis of Variance

	Degrees of Freedom	Total Variance	Mean Variance	Standard Deviation	log. Standard Deviation	Standard Error of the Difference of Means
Blocks	4	223·1984				
Treatments	4	268·1624	67·0406	8·188	2·1027	
Experimental Error	16	91·5416	5·72135	2·392	0·8722	7·3%
Total	24	582·9024			Z = 1·2305	

1% point $n_1=4$, $n_2=16$ is 0 7814; Z is significant

TABLE II

PERADENIYA PADDY STATION

Season Yala 1932

Manurial Trial on $\frac{1}{100}$ Acre Plots

Residual Effects

Yields in Pounds

Treatment	Replications a	b	c	d	e	Total	Mean	Per cent.	Remarks
Ammonium phosphate	9·5	9·6	11·8	10·0	12·4	53·3	10·7	103·2	
Superphosphate + Green Manure	9·8	15·0	10·7	9·9	11·1	56·5	11·3	109·3	
Superphosphate	10·4	13·2	11·8	11·4	11·9	58·7	11·7	113·5	Treatments appear in the same
Green manure	9·2	7·1	8·5	7·7	12·2	44·7	8·9	86·5	order as in the *Maha* records.
Control	11·1	12·2	10·8	7·3	10·3	51·7	10·3	100	Order of merit 3, 2, 1, 5, 4.
Block totals	50·0	57·1	53·6	46·3	57·9	264·9	10·6		

Analysis of Variance

	Degrees of Freedom	Total Variance	Mean Variance	Standard Deviation	$\log_e$ Standard Deviation	Standard Error of the Difference of Means
Blocks	4	19·0136				
Treatments	4	23·0816	5·7704	2·402	0·8763	
Experimental Error	16	38·8944	2·4309	1·559	0·4441	9·3%
Total	24	80.9896		Z =	0·4322	

5 % point $n_1 = 4$. $n_2 = 16$ is 0.5505 ; Z is not significant